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Wall cladding defects and their diagnosis

Two kinds of defects in cladding cause particular concern: rain penetration and dislodgement. Both are important in themselves. Unless rectified when warning signs appear, further deterioration is likely. Diagnosis of potential dislodgement of cladding over public ways is particularly important. This digest gives guidance on how to spot latent defects likely to lead to rain penetration or dislodgement and how to interpret warning signs. Unless warning signs are correctly interpreted, remedial work can be unsuitable and may even make matters worse. This digest deals with non-loadbearing cladding. Defects arising from external causes affecting the building as a whole (foundation movements, fire etc.) are not discussed.

Key issues: fixing, bearings, joints

The potential defects considered, rain penetration and dislodgement, can have a variety of origins as indicated in the following tables. However, inadequacies in fixings, bearings and joints have one potential origin in common: movements and inaccuracies which exceed the provision made in design. Faults of this kind may be local or general in the cladding: probably few claddings are totally free of them.

Inspection and diagnosis should, therefore, particularly try to assess whether the construction of fixings, tie-backs and supports has overcome inaccuracies without loss of security and durability, and whether joints are within their working limits of size and likely to remain so. Inspection and diagnosis should take into account that the life of many sealants, even under ideal conditions of use, is usually considerably less than that of the cladding and in some cases may be only about five years.

Differential movements are a common source of defects. While inspection and diagnosis should be made with all the potential causes of such movements in mind, particular consideration should be given to long term shrinkage and creep in in-situ concrete structures. Because of the effects of vertical loads, the amount of movement per unit length is greater in the vertical than the horizontal direction. Where the structure frame can creep independently of the cladding, the differential between cladding and structure will be progressively greater towards the top. This differential movement is potentially damaging unless compressible horizontal joints are used in the cladding. As a guide to the adequacy of horizontal compression joints, the total reduction in the height of a reinforced concrete-framed structure can be of the order of 30 mm in 30 m. During inspections, a particular watch should be kept for joints that are closed or nearly closed and for excessive areas of cladding in which joints are filled with mortar.

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Technical enquiries arising from this Digest should be directed to Building Research Advisory Service at the above address.

Detection of latent defects

Some defects may not be apparent from visual inspection and may be revealed only by dismantling or discovered by studying project documentation (drawings, specifications, etc) or records of previous repairs. No building owner wants to have work opened up unnecessarily. But where a serious defect is reported in similar buildings, or inspection shows that design or construction is substandard so that there is a risk of serious defects, opening up may be necessary. The construction drawings for the building are useful in diagnosis and wherever possible should be obtained and kept with maintenance records. However, they must be interpreted with care: they represent an idealised condition and may not show construction modifications even where these provided acceptable and satisfactory solutions to unforeseen problems arising during construction.

Many cladding defects are traceable to faults present from the start, pointing to the value of thorough inspection before the building is handed over. To be effective, initial inspection should go beyond items such as paintwork, aiming to spot items that, though minor at the time, may be early indications of significant defects.

Inspections at appropriate intervals can provide the opportunity to spot latent defects before they become serious. The frequency of inspection should take account of the age and previous performance of a building, its importance and its proximity to areas open to the public: Table 1 suggests a programme.

Table 1 Building facades: illustrative frequency of inspection

New buildings; older buildings after major alterations and repairs	Initially and then annually for first five years
Parts of all buildings where risk of damage by vandals or vehicle impact	Annually
Parts of buildings subject to severe exposure conditions, including all work above ninth floor of high structures	Every third year
Parts of all buildings over public areas	Every third year and after severe gales, heavy snowfall or other extremes of weather
Other buildings, and other parts of buildings in the categories above	Every five years, or when repainting is being scheduled if more frequent*
Parts of buildings known to contain latent defects	As appropriate to the nature and seriousness of the defect

*There are advantages in inspecting for defects during an inspection of the exterior of a building preparatory to repainting: warning signs of latent defects will not have been obscured by recent paintwork; making good of work opened up for inspection can be included in the repainting contract; any special provision needed for access can serve both purposes.

Places where defects are likely will be where exposure is greater (eg parapets) and where movement may show first (eg salient angles) because of a change in built form or at joints between different materials.

Design or construction faults might generate defects and the aim is to think what provisions ought to have been made and to see, or assess indirectly, if they have been.

What to look for

In all cases it is important to see whether a defect is repeated in a consistent pattern which may indicate how serious it is and provide clues to its diagnosis.

Defects which in themselves may be minor but, if not remedied, will lead to more serious defects. An example is a defective rainwater gutter or downpipe which, if not replaced will cause damp penetration followed by corrosion of metals, rotting of wood, frost damage and so on.

On cladding units or materials, look for cracks, spalling, staining, looseness and misalignment. For example, on concrete panels, iron stains may indicate iron-bearing aggregate (unsightly but not serious) or, if accompanied by cracking, may be an early indication that reinforcement or fixings are corroding: a more serious defect; check whether other units are stained and whether the pattern of reinforcement or fixing locations is apparent (see Table 2).

On jointing materials, signs that are common to both vertical and horizontal joints (eg hardening and splitting of a sealant) indicating ageing of the materials; signs that are different in horizontal and vertical joints (eg diagonal creases in the sealant in one but not the other) indicating the presence, the amount and the direction of relative movement (see Table 2). Where open-drained vertical joints are used, check that baffles are tucked under the flashing at the head and extend to the foot of the joint. Examine flashings at joint intersections to see if rainwater can gain access beneath them. Note that vertical open-drained joints will not function as such when used on sloping surfaces. (They will function as single-stage joints sealed at the back, their effectiveness depending wholly on the seal).

On cladding generally, signs of defects that seem related to particular locations, for example at changes in cladding materials, between cladding and in-situ work, and at salient or re-entrant angles; also at locations most exposed to weather, such as parapets (see Table 3). Look also for incorrectly detailed or badly executed work, for example, absence of throating under sills and copings (see Table 4).

On fixings, where accessible, look for indications that parts of them are absent or that there are gaps between parts intended to be tightly bolted. Check

for signs of distortion or displacement that might indicate overloading, and particularly for corrosion, even if it appears only superficial. Where the particular combination of dissimilar metals has required the use of isolating sleeves and washers, check that these have been correctly and consistently used. Corrosion of fixings not accessible for inspection may be indicated by staining or disruptive expansion at points where fixings might be expected. Look also for indications of localised damage near fixing points, for example in GRP cladding. These may be due to forces exerted by the over-tightening of fixings, or to the restraint offered to intended cladding movement by over-tight fixings.

Design provision in fixings for construction inaccuracies is often inadequate to accommodate the worst inaccuracies that occur on site, and ill-considered modifications to surmount the problem may have produced insecure fixings. Look for excessive overhangs and for improvised packing pieces particularly of degradable materials. Examples are the use of excessive packings on bolts, reducing the depth of engagement of the threaded portions. The packings used may have been the first to come to hand, such as plain mild steel washers. Look also at restraining dowels to see whether the protruding lengths are large or differing, indicating that they do not all engage fully in their pockets. Packing pieces intended as temporary supports or spacers may not have been removed after final fixing. If of unprotected mild steel, the expansion accompanying their corrosion may displace cladding. Their presence may also concentrate cladding movement at unforeseen positions.

The conditions in the cavity should be noted, looking particularly for signs of persistent damp due to rain penetration or condensation. If the conditions seem likely to encourage corrosion of fixings, inspect a 'sample' of fixings in similar locations. If a significantly corroded or otherwise unsatisfactory fixing is found, a general inspection of such fixings may be necessary. Except in these circumstances it will not usually be practicable to examine more than one or two major fixings in any one routine inspection. The inspection notes should record the location of the fixings examined so that, if they were found to be satisfactory, future inspections can include fixings at other locations.

When cladding is of bricks, stone or pre-cast concrete, the major fixings are not readily accessible for a routine inspection. It may be possible however to inspect at a particular location in the cladding (eg by removal of a parapet coping) to identify the type of fixing and make an assessment of the restraint that fixings might offer to dislodgement of cladding by thermal or other movements. Such inspection would certainly be justified if there are indications (such as closure of joints, cracking, spalling) that the cladding is subject to either vertical or horizontal compression.

If direct inspection of fixings is not practicable at any point, some evidence of their effectiveness (or of their possible omission during construction) can be adduced from the construction or the condition of the cladding. In brick cladding, for example, it is more probable that ties will be absent if the inner leaf is of in-situ concrete than if it were also of brick. If misalignment of adjacent cladding units in stone or pre-cast concrete facing appears greater than 2 or 3 mm it is possible that a fixing is defective or absent. In some cases, inspection of concealed parts can be made using fibre optics equipment.

Correct diagnosis is not unlike the detection of crime, in that it is a matter of gathering evidence and testing it critically for compliance with known facts. Some of the questions that should be asked about apparent evidence are listed in Table 5.

How to record the findings

It is important to record the findings of an inspection, including even apparently trivial pieces of evidence, so that:

- future routine inspections can include items thought suspect;
- the development of early signs of latent defects can be related to passage of time (as important evidence about their nature and origin);
- current and immediate past environmental conditions at different inspections can be compared as part of the evidence;
- the location of early signs of potential defects can be found for future inspections.

Sketches (identified as to location and date, including the year) should be made of actual or potential defects and annotated with relevant dimensional information (for example, joint width and taper in elevation, misalignment of faces on either side of joint). Photographs are often useful and those of the 'instant' kind can be annotated at once with location, orientation and date, and particular features ringed or arrowed. Careful subsequent examination of a photograph can sometimes draw attention to features overlooked in the inspection proper. An inspection record should be drawn up to reflect the features of the building concerned, but a basis that may be useful for development in this way is provided in Table 6.

Tables 2, 3 and 4 list some of the indications of potential or extant defects. The lists cannot be exhaustive because of the almost infinite variety of construction forms, materials and conditions. They do, however, represent a typical set of faults and defects and, perhaps more important, indicate how a systematic approach may be applied.

Table 2 Latent defects indicated by pattern of occurrence

Indication	Significance
Walls constructed of clay brickwork	
*Fair-faced brickwork, rendered brickwork and brickwork finished with mosaic or tile**	
(1) Cracks, predominantly horizontal and at bed-joint intervals.	May be sulphate attack of mortar. Requires presence of sulphates, cement and persistent dampness – the cause of which should be sought.
(2) Cracks at bed-joints at regular intervals of coursing.	May be corrosion of wall ties.
(3) 'Hollowness' or detachment of rendering or render coat for tiles.	May be sulphate attack as above.
(4) General fine cracking in rendered finishes.	May be due to initial drying shrinkage in rendering; may lead to rain penetration and promote sulphate attack as above.
Fair-faced brickwork (wall appears faced with bricks but brick slips used to face floor slabs)	
(5) Cracks, later spalling and possibly outward displacement, all at or near floor levels.	Suspect that brick slips used at floor levels; shrinkage in height of structural frame permits dead-load of brickwork to be transferred eccentrically to brick slips. If 'soft' joints appear to have been provided they may be inoperative (seek reason). Dislodgement of slips may occur; security of remainder dependent upon bearings and ties. Moisture expansion of bricks may contribute.
*Mosaic and tile finishes are commonly bedded on a cement-based rendering applied to brickwork, blockwork, in-situ or precast concrete or combinations of these, for example a brick panel in a concrete frame. Most failures are of the rendering rather than the tile finish. Failure may be due to sulphate attack, movement of the background, differential movement between different backgrounds, or to movements in the rendering, for example, rain penetration via the joints in the tiling may produce moisture movement in the rendering. All of these may cause loss of adhesion between rendering and background. Detachment of tiles at the adhesive layer is often due to delay between application of adhesive and positioning of tiles. Where adhesive was applied with a notched trowel the presence of an undisturbed notched pattern where tiles have become detached may be a supporting indication of the cause.	
Stone or pre-cast concrete cladding	
Non-loadbearing cladding formed by stone or pre-cast concrete facing units	
(6) Cracks, uniform in width or closed; at a later stage, spalling especially at edges or corners of cladding units, possibly accompanied by misalignment of faces.	Cladding units under compression due to inadequate allowance for differential movement between cladding and supporting structure; more likely to occur where structure is in-situ concrete. Check provision and effectiveness of horizontal 'soft' compression joints. Check for corrosion of reinforcement.
(7) Cracking or spalling of cladding units in a regular pattern which seems to indicate position of fixings; no evidence of compression (see 5).	Possible corrosion of ferrous fixings: check from drawings or specification. If serious, remove unit, otherwise keep under observation.
(8) Misalignment between faces of adjoining units.	If excessive, suspect either potential compression failure (see 5) or fixings absent or defective.
(9) Iron stains on surface of pre-cast concrete units, random occurrence.	If units unreinforced, likely to be iron-bearing aggregate. If reinforced, (see 10).
(10) Iron stains on surface of pre-cast concrete units, occurrence suggests a pattern.	If units reinforced, likely to be corrosion of reinforcement. If adequate cover, suspect also possible use of excessive calcium chloride in manufacture, especially if cracking or spalling evident; check whether defect occurs with particular units which may have been replacements for units damaged during construction and calcium chloride used to speed up casting of replacements.
Sealant-filled joints	
Horizontal 'soft' joints, often at storey-height intervals, provided to avoid compression of cladding	
(11) Sealant considerably extruded from joint or wholly extruded and edges of cladding units in contact.	Insufficient allowance for movements; risk of future cracking, spalling or displacement of cladding. If apparent within first 5 years, keep under annual observation.
(12) Sealant not deformed, suggesting no compression occurring at joint.	Beware – compression joint may be inoperative due for example to the concealed presence in it of mortar or other solid incompressible material. Examine cladding for indications of compressive stress (see 5 and 7).
Compression joints and all other sealant-filled joints in cladding	
(13) Sealant wrinkled at an angle to the line of the joint.	Sign of differential movement between cladding units in the direction of the line of the joint; seek cause and assess consequences.
(14) Sealant split or adhesion lost.	Greater movement at joint than can be accommodated, especially by aged sealants; more likely to lead to rain penetration into impermeable cladding than into brick cladding.
Light cladding, curtain walling	
Aluminium alloy framed light cladding and curtain walling	
(15) Cracks, loss of adhesion, of sealant at joints between frame members.	Frame may be assembled from separate mullions, transoms, etc, so that thermal movements are concentrated at butt joints, for example, between transom and mullion, leading to failure of sealant. May often lead to rain penetration either directly into building (especially at bottom corners of fixed glazing or spandrel panels) or via hollow extruded frame members to other points, including cavities between cladding and structure.
Aluminium alloy or steel-framed cladding	
(16) Glazing (or spandrel) retaining beads distorted.	May have been distorted by cleaning cradle or ladders or during replacement of broken glazing. If beads are 'sprung on' (as opposed to screwed) check their security and that sealant makes good contact.
(17) Glazing (or spandrel) sealant not in contact with glass or panel.	Spacers omitted or of insufficient thickness, so that movement of glass or panel under wind load displaces sealant. In this condition rainwater may be 'pumped' past the joint by repeated movement.

Table 3 Latent defects indicated by location of occurrence

Indication	Significance
Observed at salient or re-entrant angles, at other changes in built form or at junctions between different materials	
(1) Cracks, predominantly horizontal, in cladding below eaves overhang, possibly later accompanied by spalling.	Thermal movement of the roof slab may be transmitted to upper part of cladding. May lead to displacement or dislodgement by a 'ratchet' effect.
(2) Tearing or loss of adhesion of sealant in vertical joints between cladding and other construction.	Thermal movements may be concentrated at these joints, especially if cladding is lightweight and thus responds quickly to temperature changes. *See also Table 2 (13).*
(3) Cracks at end of projecting stone or pre-cast concrete window sills in stone or pre-cast concrete cladding.	Sill may be firmly held within opening in structure, but projects through cladding facing. Differential movement between cladding and structure may apply bending load to sill.
Observed on parapets of brickwork, including rendered brickwork with or without mosaic or tile finish	
(4) Horizontal cracks at bed-joint intervals.	Probably sulphate attack of mortar (requires presence of cement, sulphates and persistent dampness (seek cause). *See also Table 2 (2).*
(5) Heavy efflorescence on either face of parapet.	May be forerunner of (4).
Observed at or near salient corners or parapets	
(6) Looseness, vibration or detachment of cladding units.	Wind loads are usually more severe at these locations and fixing weaknesses may show here first.

Table 4 Design or construction faults or omissions: for use in interpretation of existing indications, or the future possibility, of latent defects

Affecting security against dislodgement

(1) Compression joints Differential movement occurs in all cases where there is a load-bearing structure and non load-bearing cladding: long-term shrinkage and creep in the structure reduce its height and apply compressive loads to cladding unless there are compressible horizontal joints of sufficient width in the cladding. If the horizontal joints between units of cladding are not compressible, compression joints, usually at storey-height spacing, are needed. These must also accommodate vertical thermal movements.

(2) Joints to accommodate horizontal movement Even where the materials used in the cladding and the structure are the same (eg steel-framed cladding to a steel-framed building), differential thermal movement will occur because of differences in mass and in exposure to solar radiation. As in (1) if joints between units of cladding are not compressible, then vertical joints to accommodate cumulative differential movement will be needed.

(3) Fixings Fixings may be designed with insufficient range of adjustability to accommodate inaccuracies, especially in the direction horizontally at right angles to the plane of the cladding and at external corners (erectors may have devised unsatisfactory expedients to overcome this problem). Fixings may restrain differential movements between cladding and structure in such a way that local stresses damage the fixings or the cladding. Isolating sleeves and washers, needed for some combinations of dissimilar metals in fixings, may have been omitted in design or construction, with risk of bimetallic corrosion.

Affecting dampness (and its consequences for rot, corrosion, chemical attack and frost resistance)

(4) Throating and 'drips' If projecting horizontal members are not profiled so as to drain water away from horizontal joints immediately above, and to shed water clear of horizontal joints immediately below, there is increased risk of rain penetration and greater reliance on initial and long-term effectiveness of the joints concerned.

(5) Flashings Flashings are used where there is an expectation that rain would otherwise penetrate; it is therefore particularly important that they are correctly installed and arranged to drain freely outward. Rain penetration may take a path underneath the flashing or through inadequately lapped and sealed joints in the length of a flashing. Drainage from the upper surface of the flashing may be obstructed. Flashings are more likely to be defective at corners, steps or other changes in geometry where they have been cut and shaped. Satisfactory performance depends on there also being a barrier or seal behind the flashing to prevent the passage of wind-blown rain; the upstand at the back of a flashing will not be sufficient protection if wind can blow through the joint.

(6) Cavity trays The latent defects are similar to those for flashings. Additionally, upstands may be of insufficient height or, especially at the ends, omitted, leading to rain penetration. Weep holes may be omitted or blocked.

(7) Cappings (eg to parapets) Metal cappings to jointed sections are prone to leakage at fixing points and at joints, where thermal movements can be large; top surfaces may not be formed with sufficient slope to provide rapid drainage.

Table 5 Testing apparent evidence

Evidence	Tests
Thermal movement	Does it appear greater on S-facing than N-facing walls? Does its timing match temperature changes (diurnal, seasonal)? Is it greater in dark-coloured components than in similar light-coloured? Does its magnitude match expected values for thermal movements? (Caution: restraints may modify movements in practice).
Moisture movement	Are the materials concerned susceptible? Does movement appear greater where construction is exposed to wetting and drying than where protected? Is the timing right?
Moisture expansion of clay brickwork	Is the timing right? (Most of the expansion occurs in the first three months of the bricks' life).
Sulphate attack of brickwork	Are all three ingredients present? (Cement, sulphate salts, persistent dampness). Is expansion greater in the height than the length of brickwork? (Caution: strictly, expansion is greater in the direction containing the greater number of joints; thus a 'soldier course' at the top of a wall expands more in the horizontal direction).
Compression of cladding	Are there compression joints in the cladding? Have they closed completely? Are they genuinely compressible or merely sealant applied over a rigid material? Or sealant concealing the edge of a supporting shelf angle? Can sources of compressive movements be identified? (eg shrinkage of reinforced concrete framed structure, moisture expansion of clay brickwork, thermal expansion of cladding).
Corrosion of reinforcement	Is there likely to be reinforcement present? Could the concrete contain chlorides? *See also Table 2 (10).* Does cracking follow a linear pattern?
Rain penetration	Could it be partly or wholly condensation? Do the conditions and construction make condensation likely? *(see below).* Could it be rising damp?
Condensation	Can the cladding 'breathe' or is it impermeable? If impermeable, especially sheet metals and glass, are cavities between structure and cladding ventilated and drained? If not, condensation on inside face of cladding is likely and accumulation of condensate is possible.
Cracking due to any supposed cause	Testing the diagnosis of the cause of a crack is often helped if the following questions are posed: Does a straightedge, applied across the crack, reveal misalignment of the faces? (may indicate lateral displacement of one part and thus the source and direction of movement). Is the crack of approximately constant width throughout its length or is it tapered, and if so, in which direction? (taper may indicate hogging or sagging). Is the crack close to short returns? (may indicate rotation of the returns and thus the direction of movement). Is the crack accompanied by spalling? (may indicate compression). Is the line of the crack at an angle to the line of the affected construction? (may indicate shear forces). Is there evidence of the age of the crack? (eg paint or organic growth on the crack faces indicate that the crack is not recent). Is there evidence of time of occurrence? (eg a crack, interrupted by uncracked mortar where scaffolding putlog holes have been made good, must have occurred before scaffolding was removed). In all cases, look for corroborative evidence provided by repetition in other similar locations.

Table 6 Basis for development of an inspection record

1 Name of inspector
2 Date of inspection
3 Weather at inspection (include temperature, rainfall)
4 Weather prior to inspection (include temperature, rainfall and any unusual climatic conditions)
5 Sketch plan and elevations as necessary, with orientation
6 Detailed sketches/photographs as necessary
7 Indications (not necessarily defects) :
in construction : cladding (or cladding components)
framing
fixings
glazing (fixed, opening)
spandrels, opaque panels
joints : vertical
horizontal
intersections
at specific locations : perimeter joints, expansion joints, joints at change of construction, compression joints
other construction
in performance : indication of rain penetration
indication of inadequate rainwater disposal (defective rainwater goods, blocked gutters etc)
indication of movement : thermal
moisture
loading, including wind
indication of relative movement
indication of cracking, displacement
indication of mechanical damage (ladders, cradles, vandalism)
indication of other performance faults
8 Assessment : indications (not necessarily defects) thought to be significant
9 Recommendations : eg inspect at next routine inspection, bring forward, further examination now, remedial action now
10 Action taken :

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